"QUICK-FIRE" PLASMA FLOW DRIVEN IMPLOSION EXPERIMENTS

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Abstract

The QUICK-FIRE experimental series presently being conducted on the SHIVA STAR fast capacitor bank (120 KV, 9.3 MJ) at the Air Force Weapons Laboratory is described. Diagnostics used to measure physical quantities are listed and preliminary results from the first eight shots are presented. Initial data indicates that the performance of the coaxial gun portion of the plasma flow switch is good. Radiation yields from the unoptimized implosions are 220 KJ of soft x-rays in the 80-280 eV range with a peak power of roughly 1.25 TW. Plans for future work are outlined.

Introduction

The QUICK-FIRE series of experiments presently being conducted on the SHIVA STAR fast capacitor bank (120 KV, 1300 microfarads, 9.3 MJ, 2 nH, risetime 2.5 microseconds) at the Air Force Weapons Lab is designed to investigate the switching of several megajoules of energy into a high speed implosion using a plasma flow switch. In the QUICK-FIRE series, SHIVA STAR is fired at 95 kV (5.9 MJ) with a total inductance of 16.5 nH.

The plasma flow switch (Figure 1) is configured as a coaxial plasma gun (Ref. 1-3). A chordal array of 120 2.0 mil aluminum wires is used to initiate the gun plasma. Below the wire array is a barrier foil of 0.12 mil mylar film which serves to inhibit premature travel down the gun of a precursor plasma generated by the explosion of the wire array. The total mass of the wire array and barrier foil is approximately 120 mg. The first five QUICK-FIRE shots were made with a 1/2 inch gap between the wire array and barrier foil, while subsequent shots used a 1/4 inch spacing.

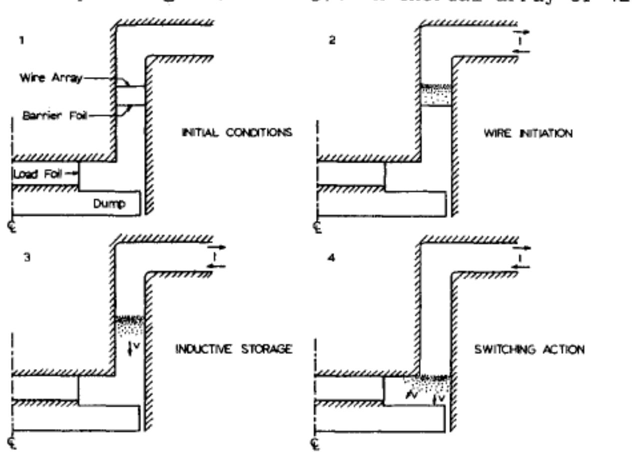

Figure 1. Plasma Flow Switch operation.

During a shot, energy from the SHIVA STAR bank is stored in a vacuum inductor as the conducting washer of plasma in the flow switch is accelerated to velocities of 7-10 cm/microsecond by 12-13 megamperes of current during the initial 3.5-3.8 microseconds of the shot. When the plasma runs off the end of the gun, current is switched into the load, which implodes in less than a microsecond, generating radiation as the plasma stagnates on the central axis. The load consists of a thin, cylindrically shaped piece of copper or aluminum plated plastic weighing between 10 and 25 milligrams.

This paper presents preliminary results from the first eight QUICK-FIRE shots. Initial indications are that the electrical performance of the gun discharge (run-down of the plasma washer) was considerably better than the transfer of current to the implosion discharge. Nearly all (80-90 percent) of the gun current reaches the end of the barrel. Of the current reaching the end of the gun, 30-75 percent is transferred to the implosion load. While the initial shots have not concentrated on optimizing implosion quality, radiation diagnostics reveal that 220 kJ of x-rays in the 80-280 eV range are typically generated during an implosion. The FWHM of the x-ray pulse is 160-180 nsec. The peak power in this portion of the x-ray spectrum is roughly 1.25 TW.

Diagnostics

Several sets of magnetic probes are installed in the barrel of the coaxial gun at various azimuthal and axial locations for the purpose of measuring the characteristics of the current sheath as the plasma washer is accelerated down the gun. A schematic drawing of a representative magnetic probe layout (QF-5) is shown in figure 2. Fast framing cameras are used to study the initiation of the wire array and provide information during the switching phase of the shot. A streak photograph of the run-down and implosion has been

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1985**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE
"Quick-Fire" Plasma Flow Driven Implosion Experiments

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Weapons Laboratory Kirtland AFB, NM 87117-6008

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**SAR**	**4**	

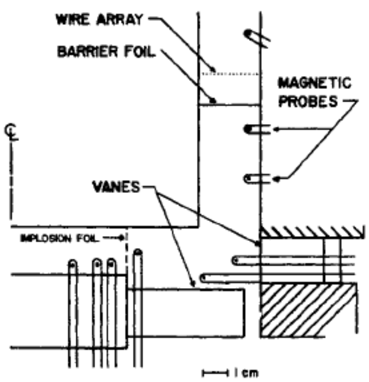

Figure 2. QF-5 Magnetic Probes

obtained. A multiple (four) nitrogen laser shadowgraphy diagnostic using the 3371 Angstrom line has been built and is being used to investigate the plasma flow during switching. The plasma current during implosion is measured by several magnetic probes on the interior of the implosion foil. A set of x-ray diodes and x-ray pinhole cameras, which view the implosion region from the radial and axial directions, together with a bolometer provide radiation yield information. Bent crystal x-ray spectometers measure line and continuum radiation. The locations of the radiation diagnostics are shown schematically in figure 3.

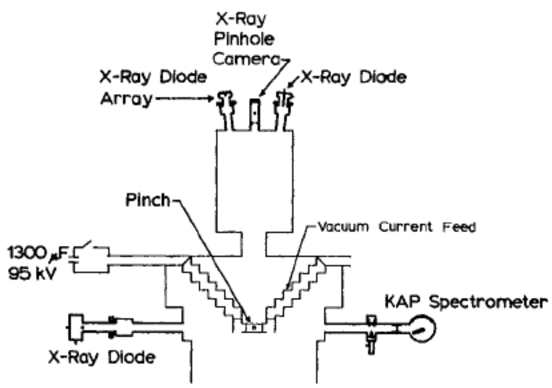

Figure 3. "QUICK-FIRE" radiation diagnostics

Data

Table 1 lists experiment parameters from several of the QUICK-FIRE shots. Figure 4 depicts traces from several magnetic probes located in the plasma gun section of the experiment. These traces are all from QF-5. Where several probes were located at the same axial height, but different azimuthal locations, the data shown has been averaged. From the measurements, we infer that about 80 percent of the 12.9 MA peak current measured above the initial position of the wire array was transported to the end of the gun. The velocity of the plasma sheath as determined by the half-height spacing between the 4.31 cm and the 7.3 cm traces was 8.0 cm/microsecond. A crude estimate of the upper limit on the density of plasma remaining inside the gun at implosion time is 3 x 10(16) cm(-3). Individual magnetic probes inside the gun during QF-5 reveal the presence of a precursor plasma carrying about 2 MA of the total current. The precursor plasma lasts for about 0.5 microseconds before main current rise. On QF-6, the spacing between the wire array and the barrier foil was reduced from 1/2 inch to 1/4 inch. The reduction in spacing did not eliminate the precursor, but it was diminished in magnitude and duration. The 10-90 percent risetime of the gun current decreases from 1.5 microseconds to 0.8 microseconds as the current sheath progresses down the barrel.

Table I

QUICK-FIRE EXPERIMENT PARAMETERS

Shot:	QF-3	QF-5	QF-7
Foil mass (micrograms/cm(-2))	202.2	314.8	mach. cyl.
Foil material	Cu-plated FV	Al-plated FV	Cu
Peak gun current (MA)	11.0	12.9	12.3
Bank voltage (KV)	95	93	89
Peak implosion current (MA)	2.3	4.8	8.2

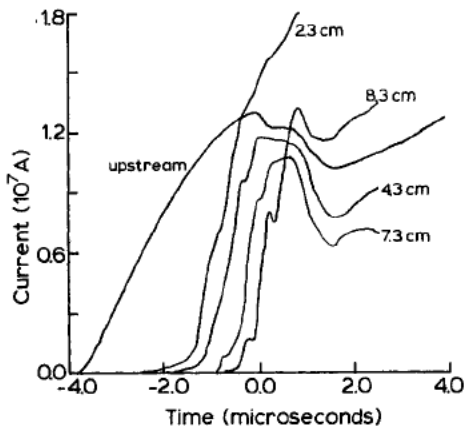

Figure 4. QF-5 gun magnetic probe data

Several traces from magnetic probes located inside the initial position of an implosion foil are shown in figure 5. Once again, this data is from QF-5. Using these measurements, we deduce that about 45 percent of the current which reaches the end of the gun is present in the implosion. An average velocity of the current carrying portion of the implosion plasma may be obtained from the intervals between the peak current points. The average velocity between the 4.1 cm probe and the 3.5 cm probe is 4.0 cm/microsecond. The average velocity between the 3.5 cm and the 2.5 cm probe is 6.7 cm/microsecond. The increase in the risetime of the implosion current as the current sheath decreases in radius is evidence of relatively poor implosion quality.

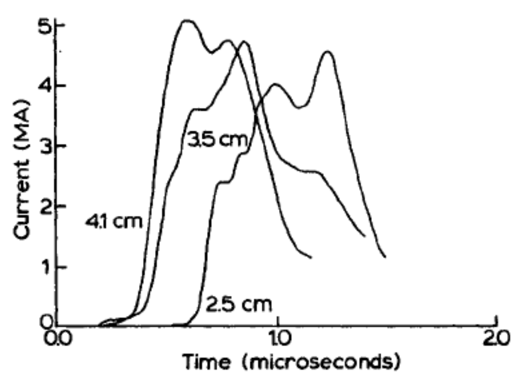

Figure 5. QF-5 implosion magnetic probe data. Numbers refer to radial position of probes.

In an attempt to fathom the mechanism of current delivery to the implosion load, QF-7 and QF-8 were conducted with a rigid cylinder machined from copper in place of

the usual foil. Magnetic probes were positioned at various radial and axial positions around the cylinder so that the probes protruded radially. A prefire which may account for the observed azimuthal current asymmetry occured on both these shots. The important results from the QF-7 and QF-8 shots indicate that a large fraction (greater than 75 percent) of the current reaching the end of the gun is being transferred to the outside of the implosion foils, and that the current rise on the outside of the implosion foils shows little evidence of a precursor current. The risetime of the current measured by the run-in probes for QF-7 and QF-8 is about 300 ns.

Table 2 lists the x-ray diode (XRD) filter energy response ranges, and Table 3 summarizes the x-ray diode data from several QUICK-FIRE shots. Data from XRDs which view the implosion region from the radial and axial directions is shown. Figure 6 shows several XRD

Table II

XRD FILTER ENERGY RESPONSE

Filter Materials	Energy Range (eV)
Bare	10-45
Al	15-73
FV (Formvar)	80-280
KF (Kimfoil)	140-280
Al+FV	370
Al+KF	500
Saran	1560-2820

Table III

QUICK-FIRE X-RAY DATA SUMMARY

Shot	XRD	FWHM (ns)	Peak Power (GW)	Energy (KJ)
QF-1	Radial FV	600	678	407
	Top KF	175	478	83.6
	Top FV	170	1312	223
QF-3	Radial KF	360	838	302
	Radial FV	320	565	181
	Top Saran	300	85	25
	Top KF	300	138	41
	Top FV	180	1256	226
	Top Al	300	382	115
QF-5	Radial Saran	160	15.2	2.4
	Top FV+Al	520	84.1	43.7
	Top FV	160	1196	191
QF-6	Top FV	120	92	11

traces from QF-3. The radial XRDs measure x-ray flux much sooner than the axial XRDs. We believe that the radial XRDs are viewing x-rays from the stagnation of the gun plasma on the dump vanes (see Figure 1) and/or x-rays from resistive heating in the initial stages of the implosion. Filtering of the radial x-rays by material ablating from the vane structure and/or the implosion electrodes may account for the absense of radial XRD signal during the implosion for the measurements shown in figure 6. The XRDs which view the implosion region from the axial direction measure x-rays exclusively from the implosion. The high energy signal from the axial XRDs (Saran filter) peaks later than the lower energy XRD (Formvar filter) which is characteristic of radiation emanating from a pinch. The QF-3 x-ray yield in the 80-280 eV range as measured by an axial XRD was nominally 226 kJ. The FWHM of the pulse was 180 ns and the peak power was 1.25 TW. The risetime of the x-ray signal was about 100 ns. The brightness temperature measured by the axial XRDs was 32-45 eV, depending on emission area assumptions.

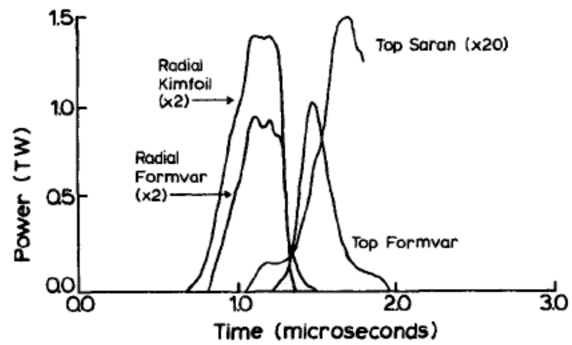

Figure 6. QF-3 x-ray diode data

Figure 7 depicts an x-ray spectrum obtained during QF-5 with a KAP convex curved crystal spectrograph. The estimated electron temperature as deduced from the Al(12+) 1s-2p vs Al(11+) 1s(2)-1s2p line ratios is 0.3-0.6 KeV. The electron density estimated from the Al(11+) 1s(2)-1s2p resonance-intercombination line ratios is 10(19) cm(-3).

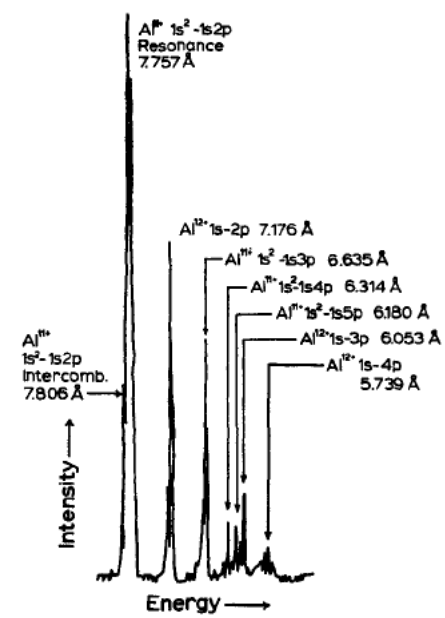

Figure 7. QF-5 x-ray spectrum

Figure 8 shows some of the data taken with a Cordin turbine camera. The picture does not show the wire array, which is clearly visible in high contrast prints.

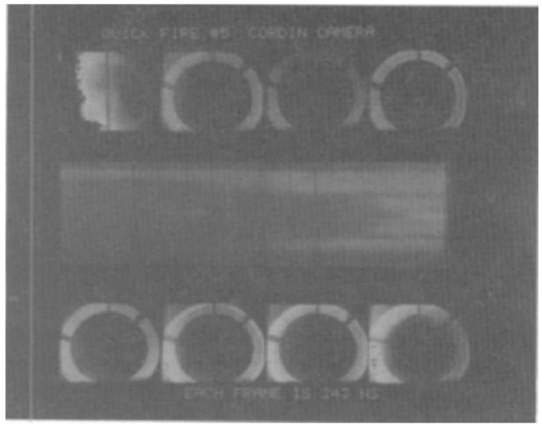

Figure 8. Cordin turbine camera photos

The wire array is visible for 0.7 microseconds after current rise. Unfortunately, the sequence of frames does not show the implosion phase of the shot. The streak photo reveals that the implosion lasted for 0.6-0.8 microseconds. Some asymmetry in the plasma exiting the gun has been observed on other shots, however, it is difficult to draw quantitative conclusions from this data.

Preliminary data from the laser shadowgraphy diagnostic indicates that the precursor plasma has a density of around a few 10(16) cm(-3). Plasmas of this density appear to have little effect on the initial condition of the implosion foil.

Conclusions/Future Work

Implosions driven by a plasma flow-switched vacuum inductive store have been achieved on SHIVA STAR. Performance of the coaxial gun has been good, although the details of events during the switching phase need to be clarified. While we have not attempted to optimize the implosion quality, x-ray yields in the 80-280 eV range of 220 kJ with 1.25 TW peak power and pulse widths of 160-180 ns are typical.

In future work, we intend to improve our understanding of processes during the switching phase of the shot using our new laser shadowgraphy diagnostic and by conducting experiments designed especially to investigate switching phenomena. Optimization of the implosion performance is, of course, the ultimate objective of the present series of experiments. Experiments using gas puffing and other techniques to improve the implosions are being prepared.

References

1. P. J. Turchi, et.al., "Development of Coaxial Plasma Guns for Power Multiplication at High Energy", Proceedings of 3rd IEEE International Pulsed Power Conference, Albuquerque, New Mexico, pp 455-462.

2. S. Seiler, et.al., "High Current Coaxial Plasma Gun Discharges Through Structured Foils", Proceedings of 4th IEEE Pulsed Power Conference, Albuquerque, New Mexico, 1983, pp 346-349.

3. P. J. Turchi, "Magnetoacoustic Model for Plasma Flow Switching", Proceedings of 4th IEEE Pulsed Power Conference, Albuquerque, New Mexico, 1983, pp 342-345.